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Design of Ground Water Remediation Control Systems at Lawrence Livermore National Laboratory.

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The Lawrence Livermore National Laboratory (LLNL) maintains an environmental remediation program, administered by the Environmental Restoration Division (ERD), to clean up contamination at its two Superfund sites: the main Livermore facility and the Site 300 experimental test site. Ground water beneath the LLNL contains volatile organic compounds (VOCs), fuel hydrocarbons, free product gasoline, chromium, lead, and tritium. LLNL started full scale ground water remediation at the Livermore site in 1989, when operations began at its first treatment facility. At present, there are five operational ground water treatment facilities at LLNL Livermore site.

Additional treatment facilities are planned for both the Livermore Site and at Site 300, LLNL's high explosive test area. All facilities are held to rigorous quality management requirements imposed by DOE and other organizations within LLNL. These include requirements for design control, performance specifications and verification, maintenance, reliability, and safety.

All treatment facility control systems are required to be highly reliable, robust, and verifiable. The systems must also allow for adaptable process configurations to provide for occasional process changes due to component failures, well field management, and remediation experiments and special measurements. They must be designed to maximize the efficiency of maintenance support over their lifetime. Future plans call for integrating the facility control systems into the established ERD networking and database systems.

Control system designs for the facilities constructed before 1994 were independently developed, resulting in little uniformity between systems. This required maintaining a broad base of specific skills used for implementation , and created inefficiencies in maintenance and upgrade efforts. The engineering team responsible for developing and maintaining the facility control systems recognized that a more unified and standardized approach would better serve the program needs.

The first step undertaken towards a more unified system was to conduct a comprehensive review of the configurations, designs, and requirements of all existing and proposed facilities. In cases where this information did not exist in written form, or was distributed among several related documents, the engineering team generated new drawings and specifications which were put through an internal review process. The critical part of the requirements specification is a rigorous failure and effects analysis. For us, this turned out to be an iterative process. A series of two or three detailed discussions involving designers from the pertinent disciplines, facility operators, and the development team produced a complete definition of the expected hazards, the failure modes that could lead to them, and the associated risks. The resulting documents fulfilled a portion of the design control requirements, and also served as a baseline for the next step. Total effort costs associated with this phase were roughly three months, with a duration of about six weeks.

As the next step, the engineering team developed a general control systems model that could be applied to all facilities. This model was constructed using Ward-Mellor[1] type object-oriented design techniques. The goal of the model development was to establish clear interface definitions and identify logical system modules. Breaking the design into modules and unambiguously defining the interfaces between these modules provides several advantages. It allows the designers to make the best choices as to which parts of the design would be implemented in hardware and which with software. Second, these clear definitions speed up the development phase by allowing the design team to concurrently develop different parts of the system, then efficiently integrate them into the complete package. A third advantage is that much of the design documentation is generated by the modeling process. Done correctly, the modularization results in a highly re-usable implementation in which later designs based on the core package are implemented by adding or removing modules. Testing and verification of these new implementations become extremely efficient, because large pieces of the logic and other mature parts of the package have been thoroughly validated. The modeling effort was largely carried out by the author, encompassing four weeks of effort over a period of two months.

With the modeling phase completed, the engineering team began making decisions on implementation details. A few fundamental choices were made first. A primary decision was selection of a PC based system over other platforms, such as Macintosh or DEC machines. The performance / price ratio of 486 and Pentium based machines, as well as the wide range of commercially available PC process control software were the main factors. The requirements for adaptability, data monitoring and logging, and networking make the PC platform a better choice than a PLC implementation, which was also considered.

Our next decision was the selection of front end instrumentation hardware. Our choice was Opto-22 systems, based on their high degree of built-in modularity, flexibility, and reliability. We have found that they are easy to expand when additional data channels are required, and the cost per channel is competitive with comparable instrumentation hardware. In addition, several members of the engineering team have extensive experience with Opto-22 instrumentation in critical applications, with exceptional performance.

The final major decision was the choice of the process control software. Packages that were primarily considered were Intec Corporation's Paragon TNT software, Intellution's Fix software, and WonderWare's software by the same name. We selected the Paragon TNT software for several reasons. It presented a more complete package that met more of our needs than the comparable other products which required additional options or third party software for the same functionality. Its client-server

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[1] These techniques are detailed in the book by P. T. Ward and S. J. Mellor, *Structured Development for Real-Time Systems*, New Jersey, Prentice-Hall, 1985.

architecture was especially suited to our modular implementation approach and its functionality / pricing options allowed us to tailor the packages to the range of implementations present in our facilities. In our opinion, it also provides the most complete suite of functions among the products considered.

As an additional part of our efforts to design systems that could be efficiently operated and maintained, we sought to identify sensors and instruments that could serve as a sort of site-wide standard. This has the advantage of efficiently providing spare components and allowing the engineering team members to become thoroughly knowledgeable in the component's operational details. Much of our interlock and safety related functions are implemented using switch type instruments. These include detection of high and low limits on temperature, pressure, and water levels. Analog instruments are primarily used to monitor the performance of the process and to report regulatory and / or hydrogeologic data. In some cases, the analog channels provide signals to software logic that determines the existence of out of tolerance conditions, which are fed into the interlock chain. We routinely make analog measurements of flow rate, water levels in extraction and monitoring wells, air flow in air sparging systems, process water pH levels, process water temperature, and current through UV lamps in UV / oxidation reactors. All analog instrumentation is selected with 4-20 mA interfaces, to simplify the interfaces and reduce noise susceptibility.

Our standardization efforts have focused mainly on flow meters, well level sensors, and pH measurement systems. Because of the high levels of silt and dissolved solids in our ground water which can clog or foul contacting type flow instruments, we have found that magnetic flow meters work best for us. Based on performance / price ratios and customer support, we have chosen Krohne brand meters for our standard implementation. They provide high accuracy and stability, and provide a wide range of options for interfacing with our control and monitoring system. For similar reasons of performance and reliability, we have selected standard instruments for pressure transducer type well level sensors (Instrumentation Northwest, Inc.), and pH probes and meters (Rosemount).

All interlock and safety related components and software have been designed and installed to adhere to strict fail-safe operation. We define this as: *any failure in any component that can affect the detection of an alarm condition will cause the system to respond in the same way that it would to the associated alarm*. We have combined signal detection, wiring designs, and software logic to create a system that can detect the failure of critical components, and react to bring the system to a safe condition. This requirement is rigorously verified by stepping through all identified fault conditions and monitoring the system response. This verification is conducted periodically (usually annually) using a formal written procedure. Any anomalies are immediately reported and corrected.

The last and very important aspect of our design effort is the operator interface. Our main goals in this area are to provide interfaces that give the facility operators and maintenance personnel a logical, straightforward, and intuitive indication of the state of the facility. These interfaces include computer displays, manual control panel layouts, and component locations and labeling. To this end, we have employed human factors engineering principles. Such factors as consistency in terms and colors, highlighting the most important information, visual and audible cues, and unobscured sight lines have all been considered. We follow written guidelines for computer display design, and have developed a virtual instrument type interface that provides a same “look and feel” to operators at all facilities. This will greatly enhance the efficiency of the facility operators, and reduce training requirements.

Control systems designed using the methods described are now in operation at two ground water treatment facilities at LLNL. Implementation and testing efforts for installing the system in the second facility were reduced by a factor of at least two over any similar effort that would have been started from scratch. Current plans are to implement this system at four other facilities during fiscal year 1996. It is expected that this design philosophy and approach will result in significant savings in operations and maintenance costs over the lifetime of these systems.

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